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Discussion

Walking through history: Changing constraints in developmental thinking

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The ‘1984 Walking’ article of Thelen et al. appeared in a time period characterized by dramatic changes in theoretical perspectives with respect to motor control. The 1960s and 1970s were the heydays of the information-processing approach with many concepts from this theoretical perspective finding their way into the fields of motor control and motor development. In the earlier eighties, ecological psychology, coordinative structure theory and dynamic systems theory were introduced (Gibson, 1987; Kelso, 1995; Kugler, Kelso, & Turvey, 1982). The research described in the article of Thelen et al. can be considered as one of the first experimental studies to test the theoretical concepts provided by these new avenues of theoretical thinking. This paper presented a new way of thinking guided by new and different constraints. Twenty years later, studies of motor development have become a major testing ground for examining the developmental implications of these new theoretical perspectives. Applying the central concepts of these perspectives to the study of infancy, with its rapid changes in perception, action and cognition, have lead to a deepened understanding of motor development. In turn, the study of infancy has served to further refine many of these concepts. This mutuality is to a large extent responsible for today’s major interest in motor development and, more particularly, in the development of motor coordination. The experiments conducted by Thelen in the early 1980s, among them those reported in the *Infant Behavior and Development*

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paper, can be considered as the starting point of a major intellectual shift in motor development and one of the major catalysts responsible for the rejuvenation of the study of motor development.

1. Theoretical implications and Thelen's paper influenced our way of doing research

Thelen et al.'s (1984) article contributes to two theoretical perspectives, the coordinative structure and dynamic systems perspectives. From each of these perspectives, we will provide an example of how this paper influenced our own developmental experiments conducted in the last decade.

From the coordinative structure perspective (Kugler et al., 1982), coordination is the problem of mastering the large number of redundant degrees of freedom involved in a particular movement (Bernstein, 1967). In order to reduce the number of degrees of freedom, task-specific musculo–skeletal organizations emerge from the underlying dynamics of the organism–environment system. These task-specific coordinative structures are guided by movement-produced information that is specific to those underlying dynamics (e.g., Kugler & Turvey, 1987). Kugler et al. (1982) proposed that development of coordination is brought about by changes in the constraints imposed upon the organism–environment system. Newell (1986) elaborated on the concept of constraints, and proposed three categories of constraints: organismic, task and environmental. These different constraints do not operate in isolation, but interact with each other, leading to a task-specific organization of the coordination pattern. The experiments of Thelen et al. explained the disappearance of newborn stepping movements as entirely consistent with the constraints perspective. Namely, changing organismic constraints, i.e., changes in the disproportionate growth of leg muscles and fat tissue influences the occurrence of leg movements. As a consequence of fat tissue growing more rapidly than muscle tissue in infancy, the relative muscle force decreases. Depending on the requirements of gravity (the environmental constraint), which are more severe for stepping in an upright position compared to kicking supine or stepping in the water, stepping movements may disappear. Thus, the occurrence of stepping movements is a consequence of the interaction between organismic (body proportions among others) and environmental constraints (the orientation to gravity).

Much of our own research has been inspired by these findings. For instance, we have examined the effect of body orientation with respect to gravity on infants' reaching and grasping (Savelsbergh & van der Kamp, 1994) and spontaneous infant arm movements (Kawai, Savelsbergh, & Wimmers, 1999). In the Savelsbergh and van der Kamp experiment, 12–27-week-old infants were seated in three positions which differed with respect to the body orientation to the gravity vector: vertical (90° from horizontal), recline (60°), and supine (0°). Balls on a black board were presented to the infants in all three positions. The number of reaching movements was affected by body orientation. Specifically, the 12–19-week-old infants showed reaching behavior in the vertical position (but not the other positions) that was equivalent to that of 20–27-week-old infants in all positions. A similar tendency was found for the quality measurements. Thus, similar to the observations of Thelen et al. on leg movements, this experiment demonstrated that the development of reaching does not just reflect maturation of the

central nervous system, but a change in the interaction between organismic (e.g., arm mass) and environmental (e.g., gravity) constraints.

A second example how the work of Thelen et al. influenced our own research concerns newborn spontaneous arm movements. We found that the frequency of occurrence of various spontaneous arm movements is greater when the newborn is positioned in a vertical position in comparison to supine position (Kawai et al., 1999). Like in the Thelen et al. paper, the ponderal index measurement correlated with the frequency of arm movements in the supine position. This has important clinical implications for using the quantity and quality of spontaneous movements as a diagnostic instrument indicating the status of the central nervous system (e.g., Prechtl, 1990). Specifically, when assessing spontaneous movements the infants body position should be taken into account.

Another closely related perspective the 1984 article contributes to is that of dynamic systems theory (Kelso, 1995; Thelen & Smith, 1994). (The scientific work in the late eighties and nineties of the last century of the Thelen group is conducted within this perspective.) Within the last decade, there has been an increase in empirical evidence that developmental processes are not smooth and monotonic, but are better characterized by phenomenon such as discontinuities, transitions, instabilities, and regressions (Savelsbergh, van der Maas, & van Geert, 1999; Thelen, 1995; Thelen & Smith, 1994). These phenomena are characteristic of non-linear dynamical processes and scientists from this perspective often search for control and order parameters. The identification of rate-limiting factors, like relative muscle force as result of ratio fat/muscle tissue, can help identify these control parameters.

In our own work, we have examined the rate-limiting factors underlying the change from reaching without grasping to reaching with grasping (Wimmers, Savelsbergh, van der Kamp, & Hartelman, 1998), based on the Thelen et al. (1984) and Savelsbergh and van der Kamp (1994) articles. In this research, we examined the following variables: crown-heel length, total body weight, arm length, arm circumference, ponderal index, arm volume, arm weight and body position relative to the horizontal. The change in grasping behavior was modeled as a Cusp Catastrophe. The model predicted that arm weight and arm circumference significant contributed to the control parameter. These two variables had their largest contribution to the asymmetry control parameter (Wimmers et al., 1998). Thus, similar to the Thelen et al. finding with regard to infant stepping, we found that particular arm proportions were related to changed in reaching and grasping.

2. Concluding remarks

The article of Thelen et al. represents a dramatic change in the theoretical approach to motor development. Although their primary intention in conducting the research in the original paper was to provide empirical evidence to provide an alternative explanation for the results of training on infant stepping reported by Zelazo (1983), the impact of the article is also (and perhaps mainly) due to the change in theoretical thinking about motor control and particularly motor development issues it stimulated. In many ways, the paper has lead to a change in constraints on the research in motor development!

In the early 1980s concepts stemming from new perspectives had begun to achieve popularity in the scientific community, but empirical data supportive of these new ideas was lacking, especially in motor development. Thelen et al.'s article provided some of the earliest support for these new emerging theoretical perspectives. The empirical strength and clarity of their results turned this paper into a citation classic.

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